Installation of the Canadian Muon Cargo Inspection System at CRL

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IMPORTANT INFORMATIVE STATEMENTS

This project, *Field Techniques for Emergency Radiobioassay CRTI 08-0241RD*, was supported by the Canadian Safety and Security Program (CSSP) which is led by Defence Research and Development Canada's Centre for Security Science, in partnership with Public Safety Canada. Partners in the project include Atomic Energy of Canada Ltd., Advanced Applied Physics Solutions (AAPS), Canada Border Services Agency, Carleton University, Health Canada, and International Safety Research Inc.. The CSSP is a federally-funded program to strengthen Canada's ability to anticipate, prevent/mitigate, prepare for, respond to, and recover from natural disasters, serious accidents, crime and terrorism through the convergence of science and technology with policy, operations and intelligence.

AECL EACL

Report, General

INSTALLATION OF THE CANADIAN MUON CARGO INSPECTION SYSTEM AT CRL

153-30100-REPT-001

Revision 0

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UNRESTRICTED ILLIMITÉ

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1. INTRODUCTION

AECL, through its partnership with Defense Research and Development Canada, under the Government of Canada's Chemical Biological Radiological Nuclear Explosive (CBRNE) Research Technology Initiative (CRTI 08-0241RD), Advanced Applied Physics Solutions (AAPS), Canada Border Services Agency, Carleton University, Health Canada and International Safety Research Inc. has committed to conduct trials at Chalk River of the Canadian muon tomography cargo inspection system. This report outlines the requirements for the installation of this system at Chalk River Laboratory.

The proposed system has been identified as a promising technology for the detection of illicit trafficking of Special Nuclear Material such as uranium and plutonium at Canada's Points of Entry and has received significant funding (2.7M CAD), under the CRTI program. The total investment in this project by all partners is 6.8M CAD.

Among all the partners, the project identified Chalk River Laboratories as the only collaboration-wide site where special nuclear materials can be obtained and tested (inside CA2) without undergoing additional licensing or approval. AECL's obligations to the project require that the infrastructure for testing special nuclear material detection, identified when the project was initiated in 2008, be secured.

The detector, also referred to as CRIPT (Cosmic Ray Inspection and Passive Tomography), will be used in a physics program that supports AECL's Science and Technology priorities: *(1) Enhance national and global nuclear security – With government and industry as partners, develop detection technologies and response capability associated with illicit production, use and transportation of nuclear materials in support of non-proliferation, safeguards and counter-terrorism; (2) Understand, prevent and mitigate risks associated with nuclear operations and activities – Ensure that nuclear activities in Canada are carried out safely, and that capability exists to assess, mitigate and respond to nuclear incidents.*

The first part of this report was written to outline the physics program of the muon tomography facility. It is by no means exhaustive and is meant to outline the current program and stimulate discussion toward expanding the usage of this facility. The second part of the report provides an overview of the system and gives a draft schedule for the installation of the CRIPT detector at AECL.

2. PHYSICS PROGRAM

Muons are charged particles, much like the electrons, created by the interaction of cosmic radiation with the upper layer of the atmosphere. They are charged like the electron, which makes them easy to detect, but have a large mass and on average a high momentum, which confer them a strong penetrating ability. Because of this unique ability to penetrate matter, and the ubiquitous presence of this natural form of radiation, cosmic ray muons have been used to image the interior of structures. First measurements date from 1955 and in 1970 Luis Alvarez dramatically demonstrated the use of cosmic-ray muons while looking for hidden chambers in the Second Pyramid of Giza [1]. Muon radiographs are still in use today as a mean to image structures of volcanoes in an attempt to predict volcanic eruptions [2].

These previous measurements were all based on the attenuation of the muon flux. Recently, a number of groups have extended the concept of muon radiography to the tracking of individual muons as they enter and exit structures. In muon tomography, the incoming and outgoing directions are recorded for each muon thereby producing a 3D image of the scattering location [3] [4].

AECL's muon facility will support the above mentioned S&T priorities through a broad scope of experimental and theoretical activities described below.

2.1 Detection of Illicit Nuclear Material in Cargo Containers

Detection of illicit nuclear material at Canada's points of entry still poses a challenge. The Canadian Border Service Agency (CBSA) has excellent systems in place to detect low level gamma radiation, but the probability of detecting nuclear weapons and Special Nuclear Materials (SNM) or well-shielded radiological sources is low. This capability gap has been recognized early as threatening operational preparedness of Canada against Radio-Nuclear (RN) security threats.

Although advances have been made in muon tomography for the effective detection of SNM, much remains to be done for the realization of an operational system. The real world constraints of a practical system require very high detection effectiveness, a low false alarm rate and speed of delivery so as not to affect the flow of commerce. These constraints require improvements to the current cargo inspection system on several fronts: advances in instrumentation, development of robust detection algorithms and engineering development of a field deployable system.

Advances in instrumentation had already been recognized by the CRIPT collaboration where it was proposed to measure muon momentum on an event-by-event basis. The momentum of the muon enters critically in the ability to speedily detect SNM. Current research at AECL showed that detection effectiveness of the cargo inspection system improves dramatically with improvements in muon momentum measurements. The current spectrometer momentum resolution (50%) is quite coarse and improvements in this area are warranted. It has been suggested that additional signatures for SNM such as neutron emission, gamma/x-ray and muonic x-rays could enhance the detection effectiveness and reduce the false alarm rate.

Imaging of the interior of cargo with just a handful of muons is a challenging problem. Current detection algorithms are based on extension to well known medical imaging techniques [5] in computed axial tomography (CAT). Although AECL has developed its own mathematical tools to image components in cargo that compare well with competing methods, the progress made so far remain meagre. Other well known imaging reconstruction methods could be applied to muon tomography and tested (i.e. iterative reconstruction algorithm such as ART – Algebraic Reconstruction Techniques) and new method developed. Additional research in this area has merit of its own for cargo inspection and it can potentially feedback in the development and advancement of medical imaging techniques [6].

In addition to all these challenges, a concept of operation still has not been demonstrated and several engineering issues must be tackled: deployability, manufacturing, ruggedness, cost, commercialization, etc. The availability of the CRIPT prototype will make it possible to pursue these engineering advances.

2.2 Nuclear Non-Proliferation & Treaty Verification

The IAEA, through its Safeguards program, assure the international community that non-nuclear weapon states are honouring their commitment not to proliferate nuclear weapons. Muon radiography and tomography may offer an attractive alternative to the remote, unattended and continuous monitoring of spent nuclear fuel. AECL [7] showed theoretically that muon radiography can potentially improve the accuracy and availability of data on the contents of spent fuel storage containers. This could be achieved in near real time, with the potential for unattended and remotely monitored operations. The muon facility can be used to experimentally demonstrate and validate these earlier calculations. Furthermore, the facility can be used to explore and expand other areas of non-proliferation: verification of Pu mass in special storage configuration; verification of small quantities of Pu in canned sampled; verification of Pu/U235 mass in various fuel assembly (MOX, etc.) and containers; characterization of Pu/U235 scraps; gross defect detection of irradiated fuel and fuel assemblies; verification of fresh fuel shipments; confirmation of design information (i.e. identification and detection of structural changes to facilities); imaging of UF6 shipping containers; characterization of liquid volumes in storage and process tanks [8].

Although calculations showed a striking improvement in the time taken to draw safeguards conclusions for spent nuclear fuel, this must be put in the context of the gap between what is required of Safeguards and the available resources which cannot continue to increase indefinitely. A truly practical solution will be one that reduces inspection efforts, reduces radiation exposure to workers and reduces the level of intrusiveness to the operation of nuclear facilities. As mentioned before, use of the muon facility will assist in the design of engineered and or commercial solutions.

As geological repository becomes a reality (i.e. Finland), safeguards methodology for difficult-to-access nuclear materials need to be devised [9]. Often, nuclear fuels are routed to their final resting place in welded or difficult-to-open containers that cannot be easily open for verification purposes. The regulatory agencies have now showed an interest in using muon tomography to insure continuity of knowledge and to provide a mean of re-verification [10].

Recent progress in nuclear disarmament efforts resulted in the adoption of an action plan for nuclear weapon states to place excess weapon-usable nuclear material under safeguards and to develop verification arrangement that would guarantee elimination of this nuclear material [12]. One option for the elimination of excess Plutonium is through immobilization with high-level nuclear waste. Bilateral agreements between nuclear weapons states call for bilateral and international monitoring measures to confirm that the countries fulfilled their obligations. The applicability of muon tomography to the re-verification of Plutonium segregation would need to be explored with the muon facility and informal discussion with the UK Atomic Weapon Establishment (AWE) indicated that they have an interest in AECL's technology. Specifically, the UK through AWE has expressed a desire to exchange information and expend on their capability in this area in collaboration with AECL.

2.3 Nuclear Waste Characterization

AECL's Nuclear Laboratories maintain a radioactive waste management program to protect public health and the environment and to ensure worker safety. This is partly implemented by a program to segregate and characterize nuclear waste. Generally, radioactive waste exhibits a wide spectrum of physical, chemical and radiological characteristics, which demands a complex and tailored waste characterization program. Although no single methodology can be adopted to treat such varied waste, strategies are beginning to emerge to develop guidance in radioactive waste characterization to facilitate long-term storage or disposal [11]. Current practice calls for establishing a process for characterizing radioactive waste during its entire life cycle, which means that the type of waste and waste form, the evolution of the waste with time, and the measurements to characterize the waste are usually identified upstream of segregation and disposal.

One of the key element of a robust characterization program involve fingerprinting the waste's radioactivity, chemical, physical, mechanical, thermal and biological properties and how they evolve through time. Several aspects of waste characterization could be address with non-destructive assay techniques such as muon imaging & tomography:

- Nature of nuclear waste and its actinide content.
- Homogeneity of the waste (i.e. sludge in tanks, in-homogeneities in cemented waste, etc.).
- Condition of the waste and waste package: breach of containment, corrosion, voids, etc.
- Waste stability (i.e. how do waste properties change with time).
- Some waste form may be difficult and/or impossible to measure and characterize using standard techniques (i.e. encapsulated alpha/beta emitters, heavily shielded waste).

Legacy waste (i.e. non-traceable history), on the other hand, offers a different challenge. The diversity of nuclear waste characteristics makes it unrealistic to look at all possible scenarios in which muon tomography can be used to characterize waste. It is conceivable however, that muon imaging could infer/confirm the presence of actinides in legacy waste.

2.4 Critical Infrastructure Protection

Critical infrastructure protection refers to maintaining the integrity of Canada's vital assets against damages from criminal acts, human errors or natural disasters. A recent analysis predicted that US government spending to safeguarding the physical integrity of transportation network, utilities, energy infrastructure and major world events (i.e. Olympics) will reach 32.6 billion USD by 2012 [13].

It has been suggested that accurate measurements of the angular distribution of cosmic muons can reveal the onset of extreme space weather about to hit the earth [14]. When solar coronal mass ejection, directed toward the earth, interact with the planet's magnetic field, strong electromagnetic currents can be induced in large infrastructure such as the electric grid, pipelines and railways. These can yield to catastrophic failures, as we have seen in 1989 in Quebec [15], with significant economic loss. Additionally, the large flux of energetic solar particles can severely affect satellites such as the GPS network with dire consequences.

A world network of muon detectors has been in operation since March 2006 [14]. Results from this network of detectors show that the onset of extreme space weather can be detected up to 9 hours prior to the arrival of the shock wave at the surface of the earth. However, coverage for the North American continent is inexistent. This is all the more surprising since Canada is the most likely country to be affected by extreme space weather given the country's proximity to the magnetic North Pole.

We plan to join the Global Muon Detector Network (GMDN) as soon as the detector is moved to Chalk River. Although the detector size is not optimum and the coverage marginal, use of the facility will allow work leading to the development of a detector system that would provide accurate coverage for the whole of North America. Thereby provide an early warning system for Canada and the US of the onset of extreme space weather.

2.5 Other Applications of muon tomography

2.5.1 Imaging Critical Facilities

The Fukushima-Daiichi reactor accident has outlined the need for a better prepared nuclear emergency response. Many questions are still unanswered following this accident. One that remains is the status of the nuclear power plant [16]. Where is the reactor fuel? Has containment been breached? Has the integrity of the spent fuel pool been maintained? Japan is currently investigating technologies that could help answer some of these questions [16]. It has been suggested very recently that muon tomography could be used to image the interior of reactor cores [17]. Work is underway at AECL to demonstrate the technology at the ZED-2 reactor with portable muon detectors.

2.5.2 Decommissioning of Nuclear Facilities

The stringent safety standards associated with the decommissioning of nuclear facilities requires a thorough assessment of the materials present. Improved imaging of nuclear facilities could potentially provide a tool to facilitate the release of materials and sites from regulatory control. In particular, if imaging of critical facilities proves successful, muon tomography has the

potential to improve the decommissioning of research reactors and small facilities. It may also be attractive for the decommissioning of some types of disused sealed radioactive sources.

2.5.3 Geotomography

A recent collaboration between AAPS and industry (Breakwater Resources Inc.) has shown that muon geotomography was feasible and can successfully identify ore bodies underground. The technique may be able to reduce exploitation costs, increase the success of exploration and reduce the environmental impact [18]. In a similar vein, geotomography has been proposed as a way to monitor geological repositories of supercritical CO_2 [19] in deep sub-surface storage.

3. INSTALLATION AT CHALK RIVER LABORATORY

After the commissioning and completion of initial testing at Carleton University, the CRIPT system (detector hardware, electronics and support structure) will be disassembled, transported to Chalk River Labs, and reassembled so that further testing can be conducted by AECL on the detection of SNM [18] but also on the physics program described above. The complexity of the prototype system, its size, more than 5 m high, and its weight almost 20 metric tons require significant infrastructure for moving the equipment. In this section we give an overview of the CRIPT system followed by the expected work or facility changes (assessment, preparation, engineering changes, etc) to accommodate the installation of the detector in the Room 123 in bldg. 145. Finally we outline the schedule for the work proposed to move the equipment at Chalk River Labs.

3.1 System Overview & Specifications

The principle of a detector system for muon tomography is shown on Figure 1. Cosmic ray muons, a naturally occurring radiation, rain downward on structures. Position sensitive detectors are placed above and below the structure to be scanned (i.e. container). A minimum of two such detectors is required for each top and bottom plane so that the muon incident and exit directions can be determined. With a simple algorithm, the image is reconstructed from the Point of Closest Approach (PoCA), i.e. the point in space that is the closest to both reconstructed tracks. Not shown on the figure are additional spectrometer planes used to measure the momentum of the outgoing muons.

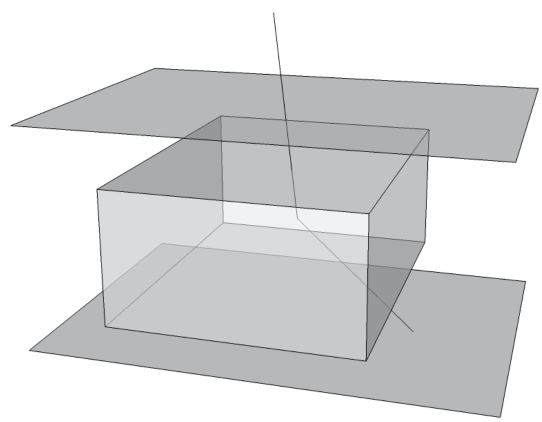


Figure 1 Concept of muon tomography

Figure 2 shows a schematic 3D view of the muon detector. The white layers represent the actual detector modules. Four detector modules are maintained in place in an upper and lower cradle, shown in grey in the figure. The yellow structure, thick iron slabs, forms, with the 2 interlaced detector layers, the muon spectrometer. In blue is the tower, which supports the upper detector structure and the cargo bay. Not shown on the figure are the data acquisition (DAQ) electronic, power supply and control computer. Figure 3 shows a picture of the CRIPT detector taken at Carleton University after installation was completed.

In appendix A Table III provides the system specifications and Table IV gives the weight breakdown of the various elements of the system. The following sections provide more details about each component.

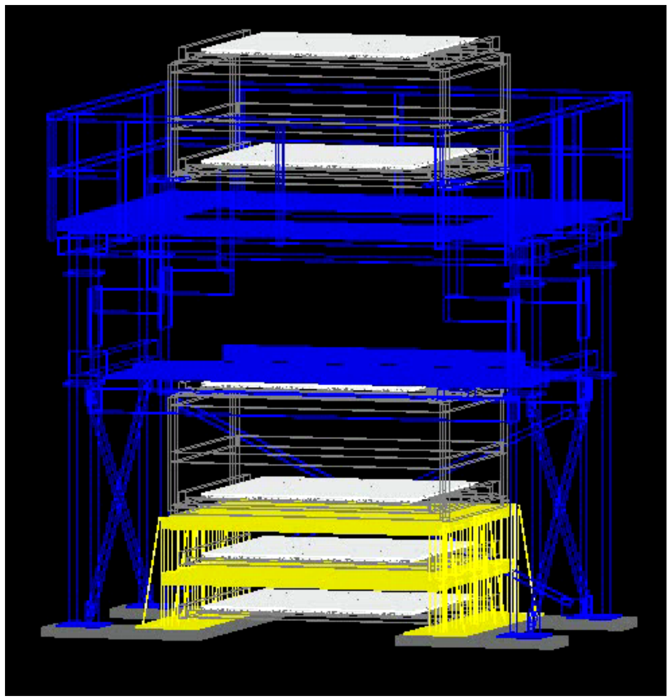


Figure 2 Schematic 3D view of the muon detector.

The white layers represent the actual detector elements. The yellow structure, thick iron slabs, forms, with the 2 interlaced detector layers, the muon spectrometer. In blue is the tower, which supports the upper detector structure and the cargo bay

Figure 3 Picture of the CRIPT detector.

3.1.1 Detector Modules (Layer)

Each detector module, or layer, is made out of 2 detector planes. Each plane measures 2 spatial coordinates of the muon trajectory. Figure 4 and Figure 5 show a prototype plane and a schematic view. In the CRIPT detector each plane is made from 123 triangular segments of extruded scintillator (polycarbonate) of base 3.3 cm and height 1.7 cm. Hence, each plane is approximately 2x2 m^2 and 1.7 cm thick. When muons strike the extrusion they produce light which is collected by a wavelength shifting (WLS) optical fibre running down the length of the triangular cell. The light from all the 123 fibres is collected into 2 multi-anode, 64 pixels, photo-multiplier tubes (PMTs). Two planes are assembled on top of each other into a detector module or layer. The layer is optically isolated with black Polyvinyl chloride (PVC) cardboard and black duck tape. Further optical isolation of the WLS fibre is achieved by encapsulating their ends into heat shrink.

Four detector modules are maintained in place by the upper and the lower cradle also referred as the Upper Tracker and Lower Tracker respectively, showed in grey in Figure 2. These frames are made of aluminium. The assembly drawing for the frame is showed in appendix B. The remaining 2 detector modules are held in place by brackets on the spectrometer unit (see section 3.1.2).

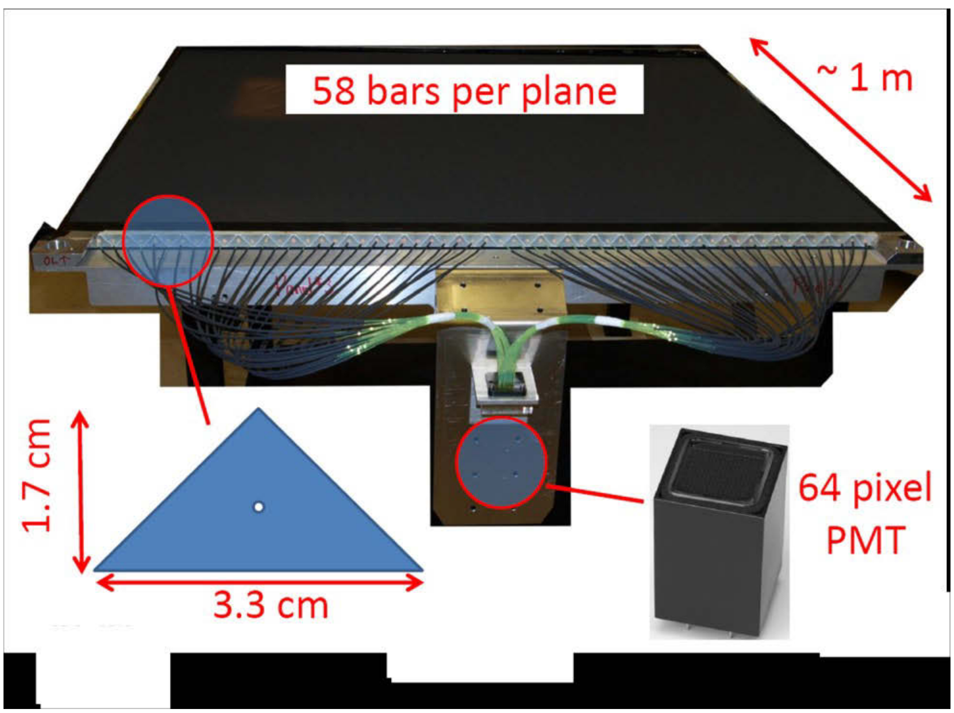


Figure 4 Prototype detector plane

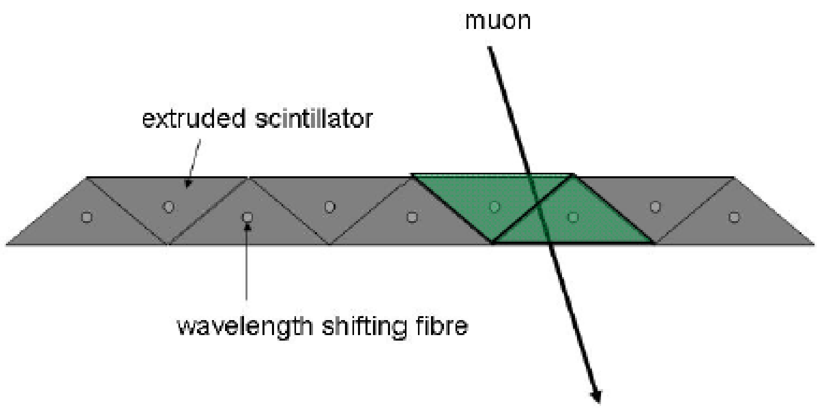


Figure 5 Detector plane schematic

3.1.2 Muon Spectrometer

The muon spectrometer (Figure 6) measures the muon momentum by measuring the angular deflection of the outgoing muon track as it traverses 2 thick iron layers, of known thickness. Each iron layer is 2x2 m^2 and is 10.1 cm thick but is divided into 4 slabs as shown in Figure 6. The spectrometer structure is interlaced with 2 detector modules and also supports the lower cradle (bottom grey structure in Figure 2). At 11.2 metric tons, it is by far the heaviest component of the detector. The spectrometer frame is made of 1 inch steel. The assembly and engineering drawings are shown in appendix C.

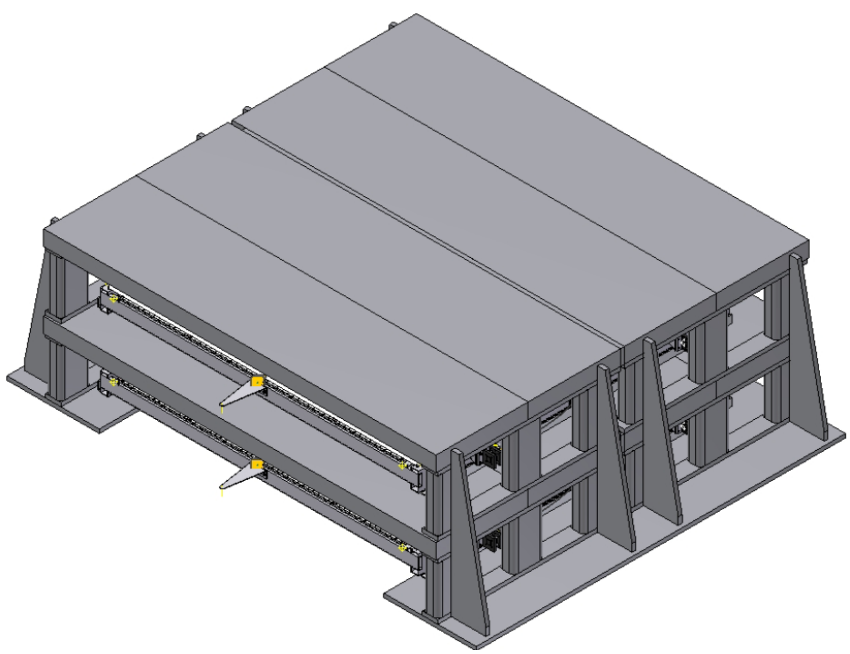


Figure 6 Drawing of the muon spectrometer

3.1.3 Support Tower

The tower, in blue in Figure 2 supports the upper detector cradle and the cargo bay. The cargo bay is defined by a space of height 163 cm and surface area 4 m^2. It was designed to accommodate a Type LD3 Unit Load Device (ULD) used to load freight and luggage in wide body aircrafts (Figure 11). The cargo rests on a 1.3 cm thick steel plate which will hold the ULD at full weight capacity (73 kg). The upper structure of the tower supports the upper detector cradle and a mezzanine with guard-rail for easy access and servicing of the detector. The mezzanine is accessed through a steel ladder. The lower cradle is not supported by the support tower but by the muon spectrometer.

3.1.4 Data Acquisition System (DAQ)

Two Multipixel photomultiplier tubes (PMT) collect light from up to 64 scintillator strips each per layer. The PMT front-end receives the optical light from the WLS fibres (not shown). Figure 7 shows the layout of one multi-anode PMT readout arrangement. Each PMT have their own high-voltage board (HVB) which also hosts current, voltage, temperature and humidity sensors. The HV, typically -900 V, is set by a DC voltage provided by the slow control card (MSCB) directly connected to the HVB. The MSCB is actuated through an Ethernet connection. The analogue signals are digitized at 50 Ms/s by a 64 channels Front End (FE) card.

The digitized signals and a time stamps from the FE card are transmitted to collector boards. Each collector board, see Figure 8, can receive signals in parallel from up to 8 FE cards. The collector (COL) board then produces coincidence events within a set time window using the FE card time stamps. Further coincidences between detector modules are realized in the master COL. Further data processing can be achieved by routing the output of the Master COL, over an Ethernet cable, to the back-end computer for data analysis. Figure 9 shows the DAQ component layout. The 4 COL cards reside in metal frame housings as part of the cradle in front of each respective layer. The HV and DAQ require less than 1500 W of electrical power.

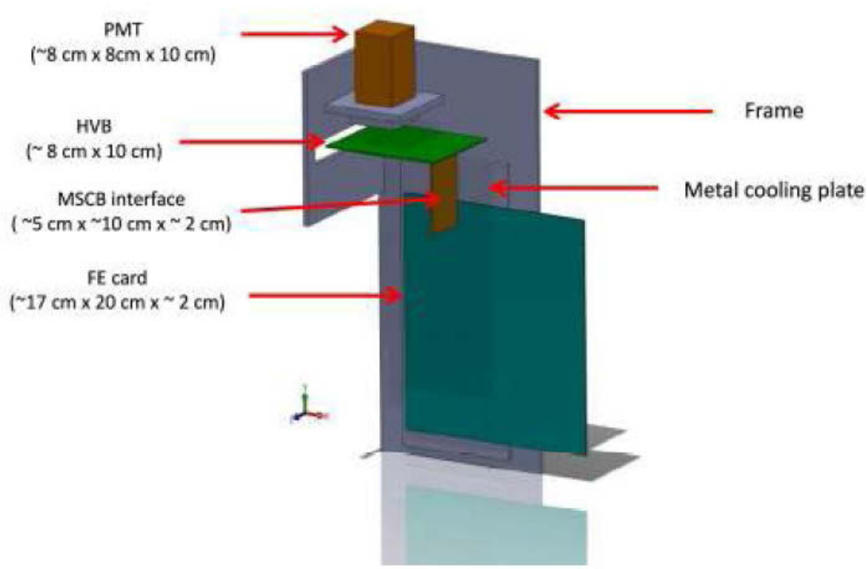


Figure 7 PMT layout arrangement showing the multi-anode PMT, the high-voltage board (HVB), the MIDAS slow control bus (MSCB) and the front-end digitizer card (FE).

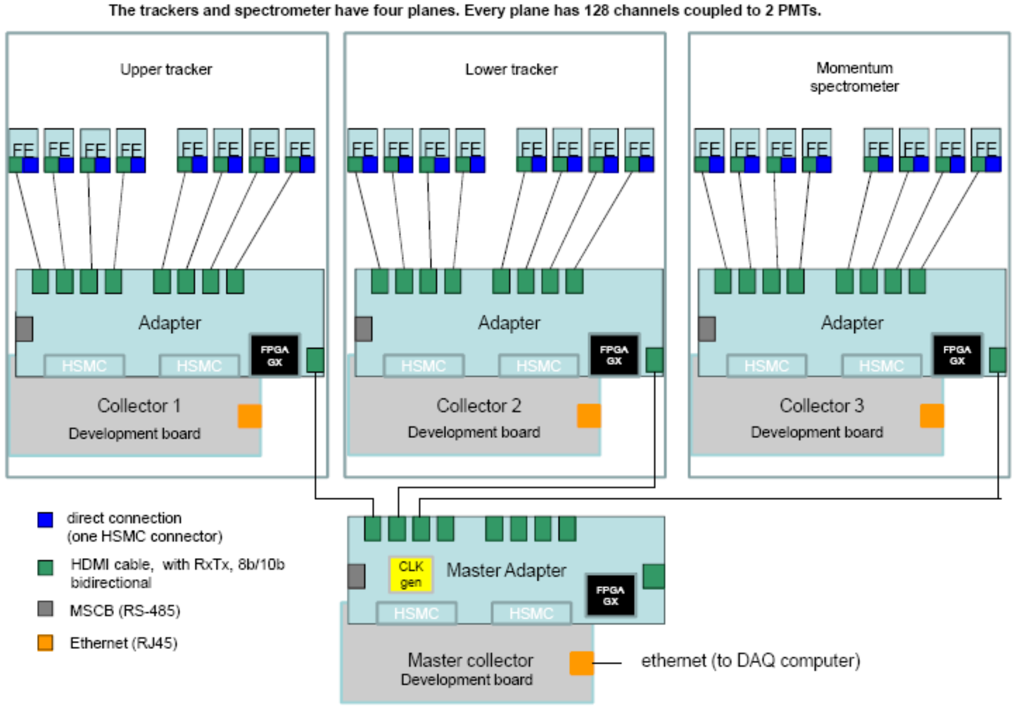


Figure 8 DAQ layout arrangement.

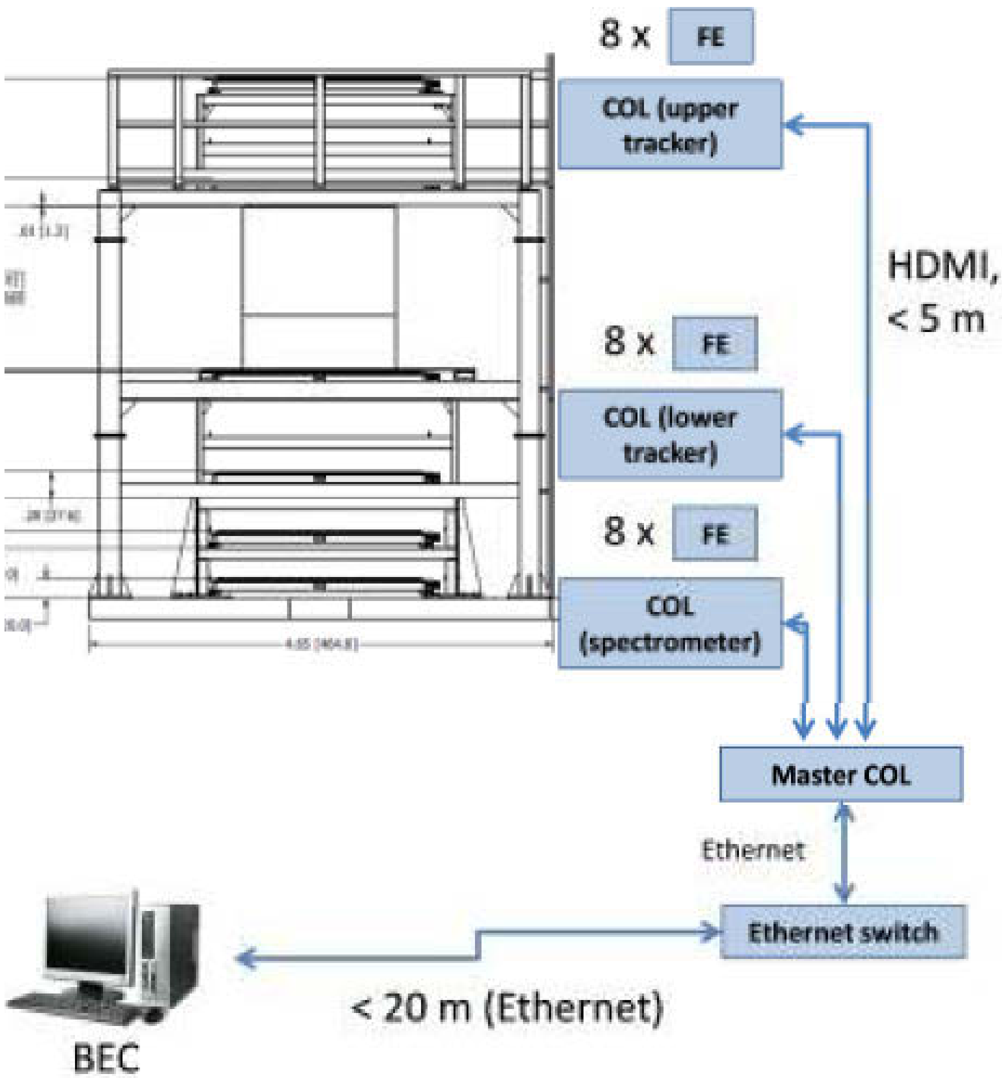


Figure 9 Electronics module layout.

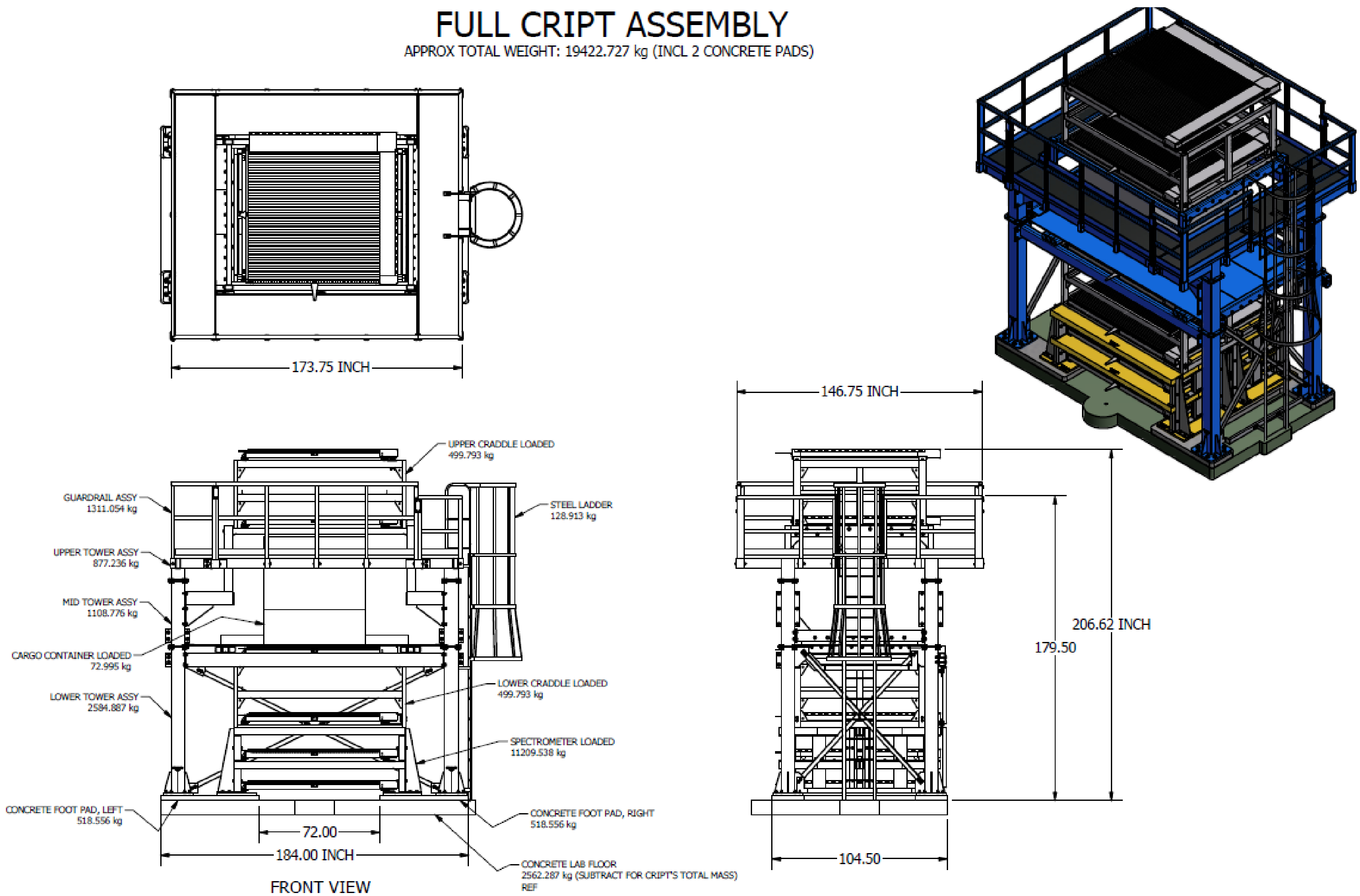


Figure 10 Assembly drawing of the CRIPT detector.

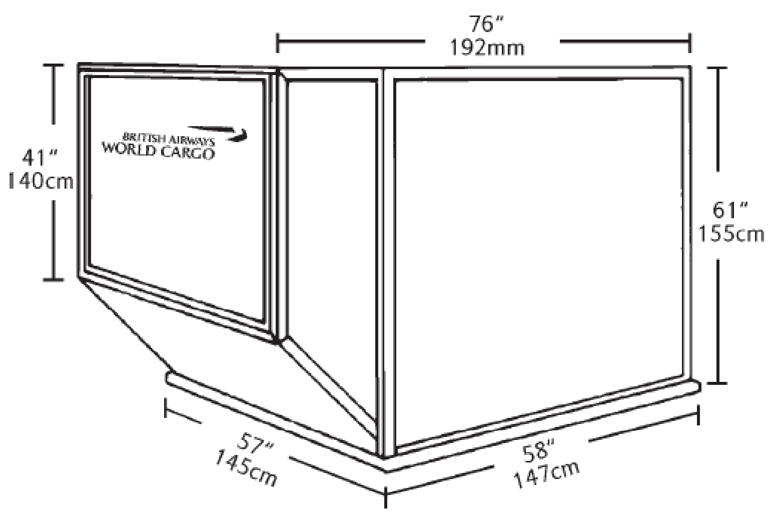
UNIT LOAD DEVICES

LD3 RATE CLASS 8

AKE

Wide body aircraft. Half width lower deck container. Suitable for the following aircraft: ■ Boeing 747, 767, 777, 757-200F

Volume	150 cu. ft. (4.2 cu. m.)
Tare weight	72 kgs/158 lbs
Max Gross Weight	1588 kgs/3493 lbs



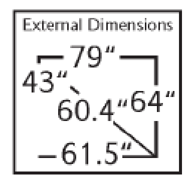
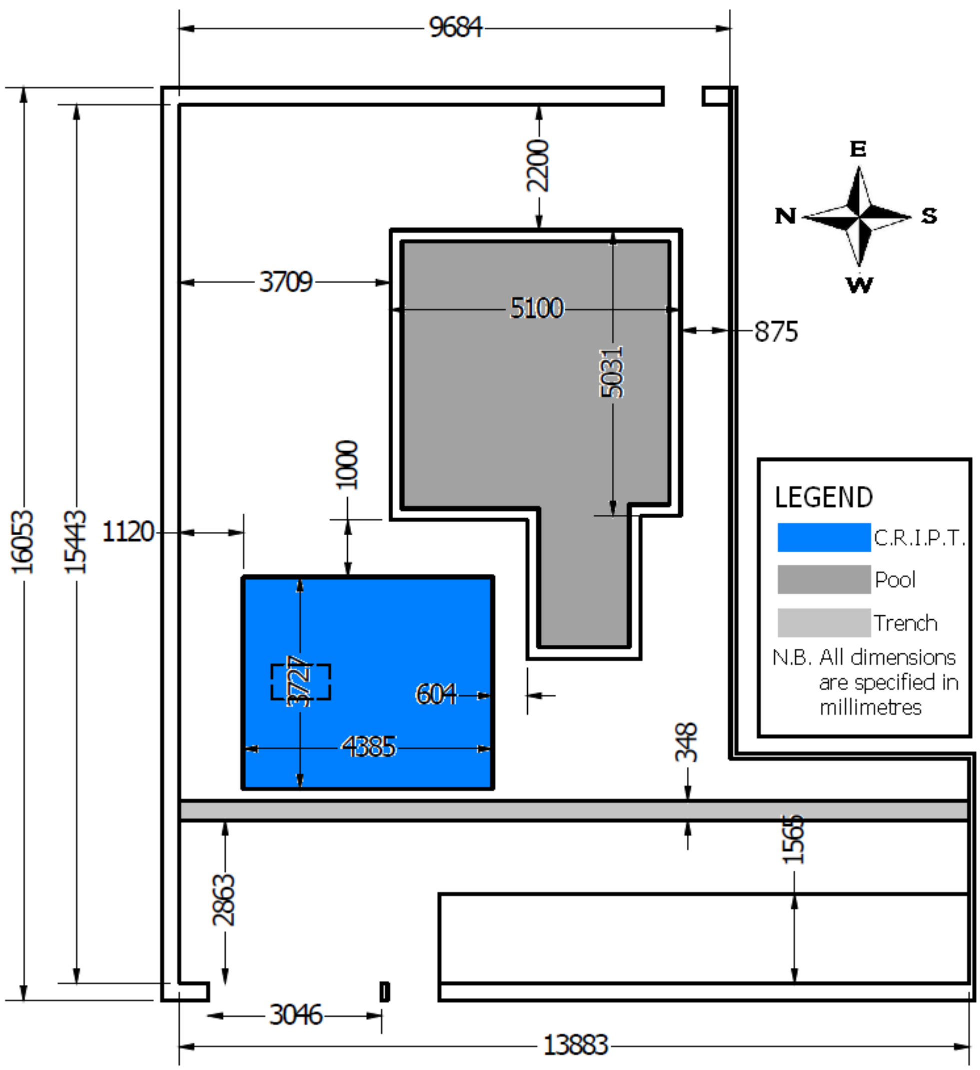


Figure 11 Type LD3 Unit Load Device (ULD).

3.2 Proposed Detector Location

Figure 12 shows the proposed detector location in bldg. 145, room 123. Bldg. 145 is in Controlled Area 2 (CA2) and room 123 is a Zone 1 area. The drawing shows, in grey, the pool area which used to house the Pool Test Reactor (PTR). We propose to place the CRIPT detector in the North-West corner as indicated in blue in the figure. In this configuration, sufficient space (1120 mm) is left on the North side to provide a means of egress in an emergency. This isle way will have to be kept clear at all time. This will meet the life safety issues [21].

In its proposed location, the detector will sit atop a 104.4 cm by 72.9 cm trap. The trap covers a trench which is no longer in use.



Proposed Placement of C.R.I.P.T. Detector in PTR Room (Room 123, Bldg. 145)

Figure 12 Room 123, bldg. 145 with proposed detector location.

3.3 Expected Facility Changes

The size of the Room 123 in bldg. 145 is clearly sufficient to accommodate the CRIPT system. Providing sufficient egress (see Figure 12) and sufficient height (11 m) to accommodate the tower. The building code requires that the structure be seismically qualified. There are reports (J.Armitage, Carleton University) on the seismic qualification assessment of the structure and the changes necessary to make the CRIPT system seismically qualified. Floor loading specification can be found in drawing number E-2206-B-3 and are 1000 lb per square foot. The floor of the room 123 cannot accommodate the current load distribution of the CRIPT tower. A concrete footing will have to be built to spread the load in order to accommodate the maximum floor loading. Figure 13 shows an example of the concrete footing used at Carleton University to spread the CRIPT detector load.

The maximum power requirement of CRIPT is 1500 W and is at the limit of what is available from a 15 A, 110 V outlet.

Optional changes to the room 123 (electrical class four, backup generator, environmental control, etc.) could be considered but are not necessary for the operation of the CRIPT detector.

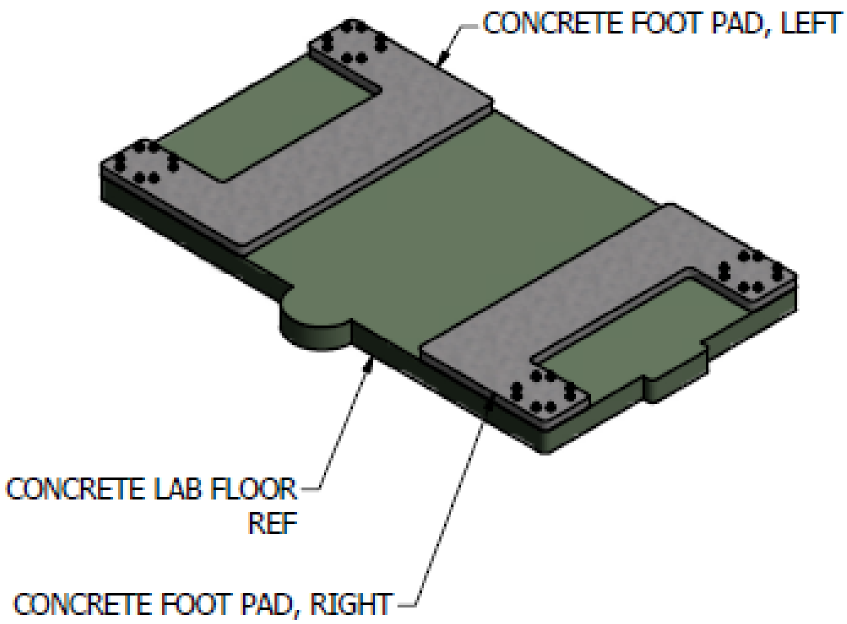


Figure 13 Preliminary design of concrete footing.

3.4 Draft Installation Plan & Costs

Figure 14, Figure 15 and Figure 16 show a draft plan of activities required for the installation of the CRIPT detector in room 123 of building 145. They can be separated in 6 distinct activities:

- PTR room preparation. This activity is almost completed. It included decommissioning activities (not shown) and room specification review (not shown), review of CRIPT detector requirements and specification, the general installation plan and the detector assembly plan.
- Engineering Change Control (ECC) activities. These include the minimum assessment and design work required for the installation of the CRIPT system: room preparation for worker safety (guardrail around the pool); floor load assessment; seismic qualification review; design of a new concrete footing; electrical requirements assessment; environmental control assessment. Table I provides a breakdown of ECC activities and cost estimates. The labour activities that, we estimate, will result are listed in the plan and in Table II where cost estimates are provided.
- CRIPT teardown and removal including packaging and loading.
- CRIPT shipping to Chalk River Labs, including unloading, un-crating and storage.
- CRIPT installation which covers all aspects of assembly, including wiring and electronics installation.
- CRIPT commissioning which includes fibre optics testing and replacement, PMT and DAQ testing and replacement and overall detector calibration.

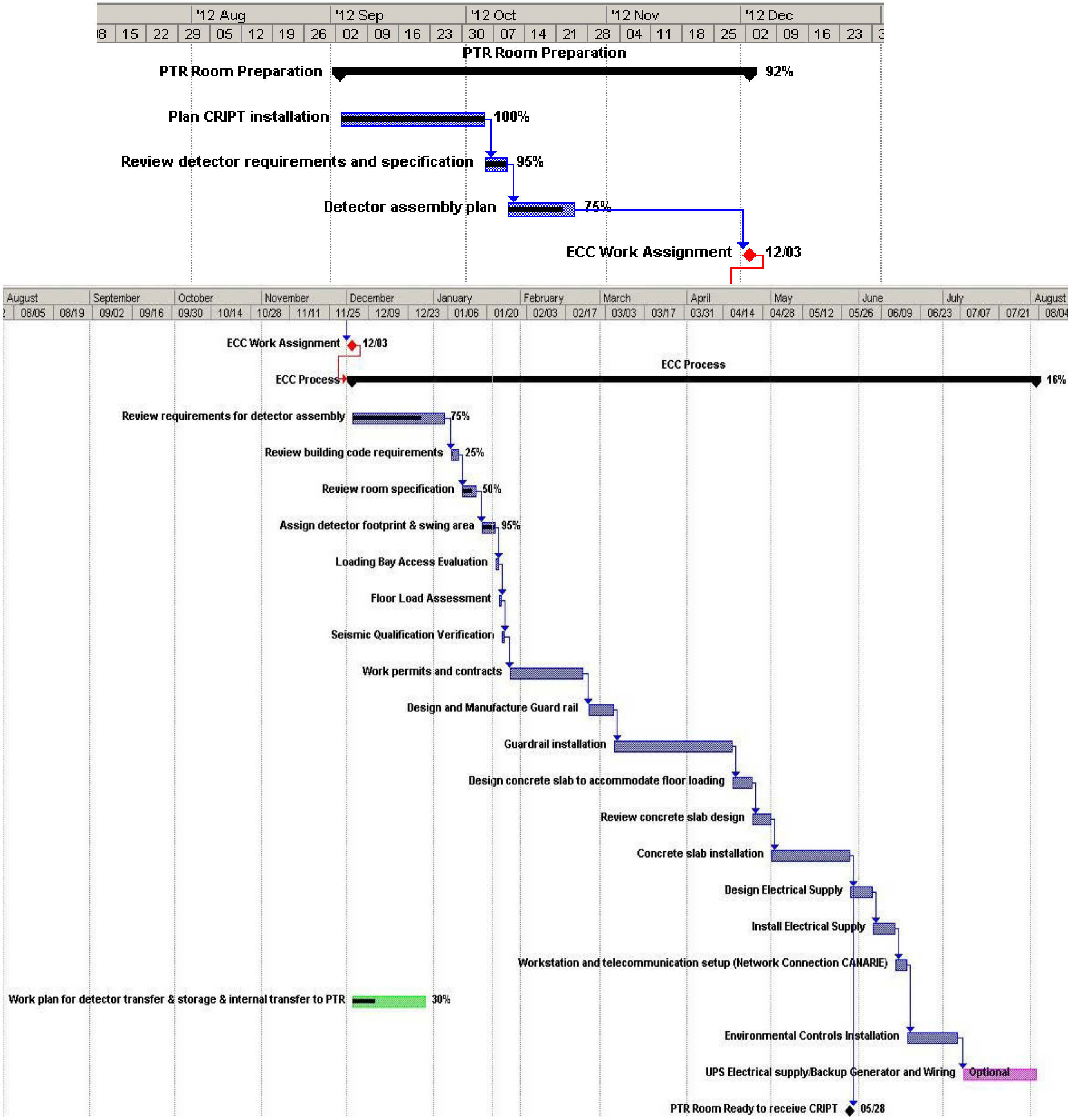


Figure 14 Plan for Room 123 preparation.

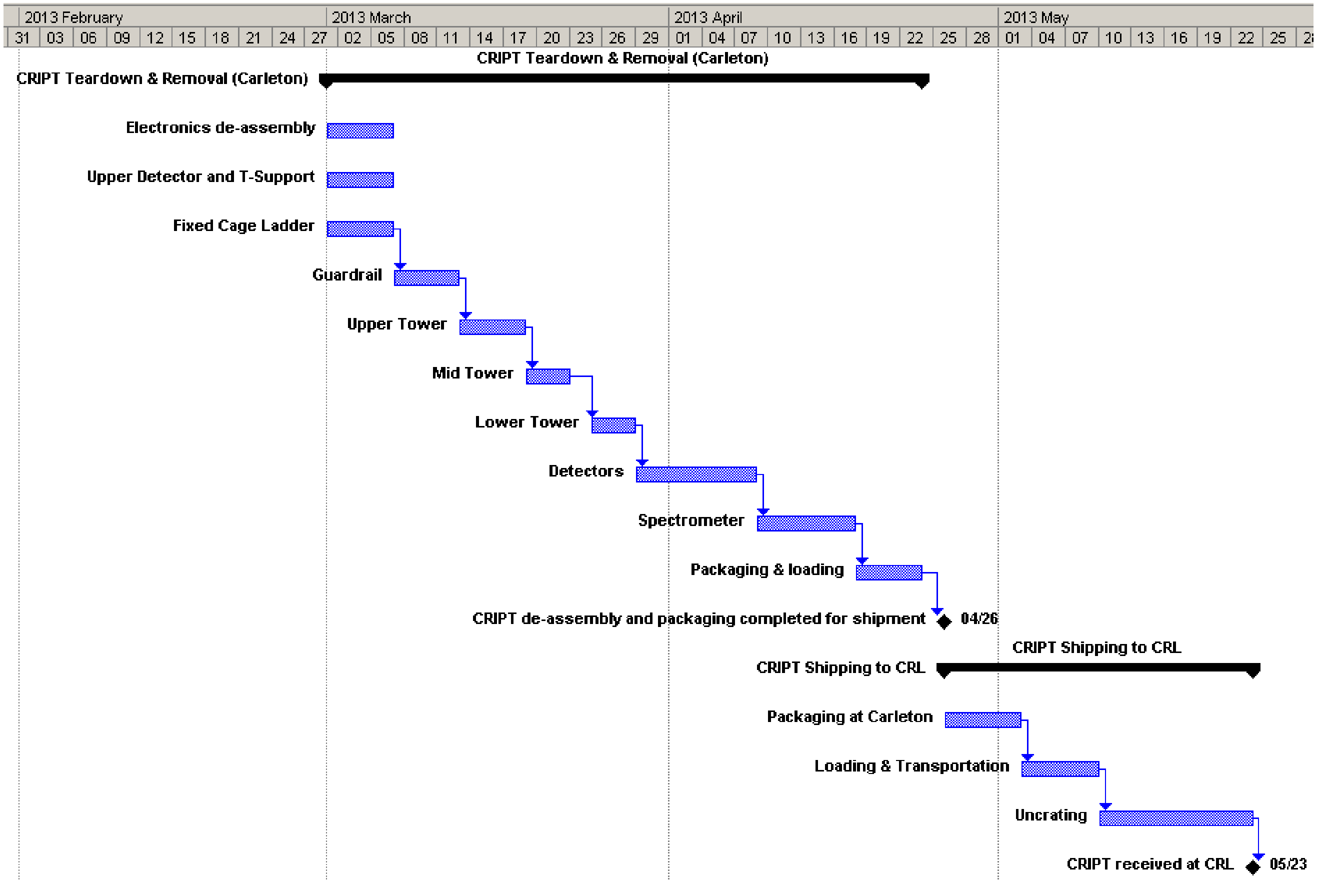


Figure 15 Plan for tear-down and shipping.

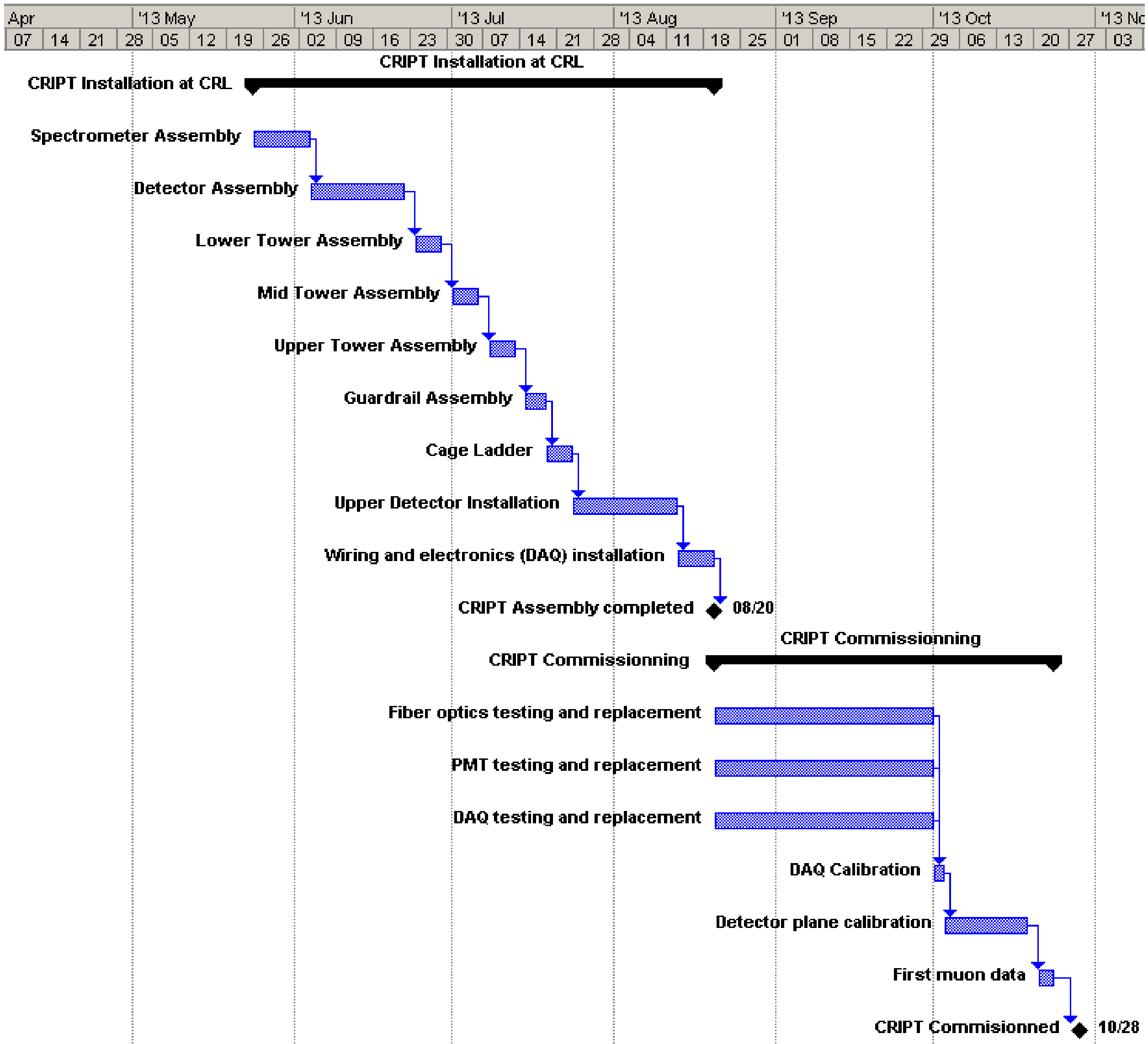


Figure 16 Plan for CRIPT installation at CRL.

Table I - AECL Design Engineering Estimates for Room 123, B. 145 ECC Jobs

CR#	REA#	Job Name	Project	Deliverable	Eng. Dept.	Cost Est. ($)
B145-30100-RREC-001	211769	Operational requirements of the Muon Tomography detector in Rm. 123, B145	Guardrail Installation: Design guardrail around pool	1 structural drawing for guardrail around pool	Structural	9500
			-Loading bay access evaluation -Floor load assessment -Seismic qualification of the detector - Recommendations for construction and installation	-1 memo authored by structural engineer regarding floor load assessment and loading bay access evaluation -Seismic qualification review of existing documentation/calculations -Excluded are any modifications to redesign CRIPT support to achieve seismic qualification. This will (if required) be addressed under separate estimate	Civil Structural	5000
			-Design reinforced concrete foundation/base for CRIPT -Design electrical supply -Work station c/w electrical, phone, computer, Ethernet connections	-1 structural drawing for new reinforced concrete slab -1 design calculations for new slab -1 electrical drawing -1 drawing for work station/electrical etc.	Civil Structural Electrical	16500
			-Environmental controls -UPS Electrical supply / back-up generator	-2 drawings for UPS and back-up generator -2 drawings for HVAC mods/additions	Civil HVAC Electrical	20,000

Note: RREC: Reduced Risk ECC; EBM: Engineering Branch Manager; ER: Engineering Representative; OR: Operations Representative; JL: Job Leader

Table II - Work Management AECL, Estimates for Labor

Job	Trade @ Hours	Total Hours	Comments
Assessors	2 people @ 37.5 hrs (1 week)	→ 75 hrs	
Concrete Pads	2-CA @ 32 hrs	→ 64 hrs	Carpenter (CA)
Assembly	2 Millwrights @ 12 weeks 1 Utility Worker @ 12 weeks 1 Heavy Equipment Operator @12 weeks	→ 960 → 480 → 480 hrs	Unloading/installation of the Muon Tomography Detector
Electrical	2 electricians @ 5 days	→ 80 hrs	Electricians (ET2); Running of a conduit, wire in the facility for the 15 amp feed and bonding of the steel structures to a building ground CA2
Commissioning	2 control maintainer (electronics) @ 3 weeks 2 electricians @ 5 days	→ 240 → 80 hrs	

4. SUMMARY

This report outlined the physics program of the muon tomography facility. It is by no means exhaustive and is meant to sketch the current program and stimulate discussion toward expanding the usage of this facility. The second part of the report provided an overview of the system and gives a draft schedule for the installation of the CRIPT detector at AECL.

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Appendix A

CRIPT Detector Specifications

Table III - Muon detector specifications

Dimensions	**Span (Inches)**	**Span (m)**
Front Width (Outer Edges of Concrete Foot Pads)	184.00	4.67
Total Height Above Foot Pads	206.62	5.25
Side Width Outer Edge of Tower Assembly Support Legs	104.50	2.65
Side Width Guardrail Assembly	146.75	3.73
Spacing Between Concrete Foot Pads	72.00	1.83
Front Width Guardrail Assembly	173.75	4.41
Height of Upper Edge of Guardrail Above Concrete Foot Pads	179.50	4.56
Side With (Outer Edge) of Concrete Foot Pads	104.50	2.65
Side Width of Spacing Between Feet of Foot Pads	66.50	1.69

Weight	**Mass (lb)**	**Mass (kg)**
Total, including maximum cargo weight	42788.5	19403.5

Power	**Consumption (W)**
HV and DAQ combined	1500.0

Loading	**Area (Inches^2)**	**Area (m^2)**
Total Area Of Spectrometer Base Footings	4404.00	2.84
Total Area of Tower Base Footings	1265.65	0.82

Table IV- Weight of detector components

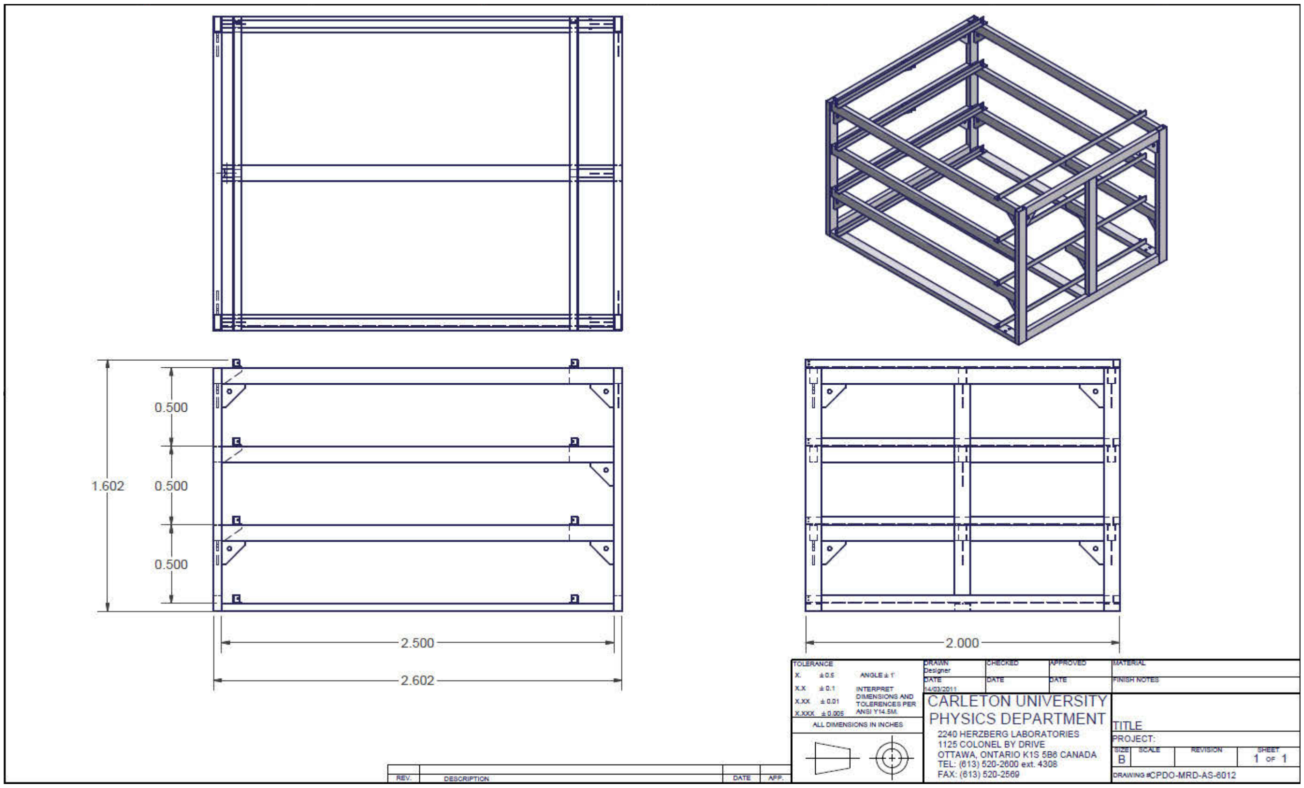
Assembly	Sub-assembly	Mass (kg)	Mass (lbs)
Upper Cradle Loaded		**516.2**	**1137.953**
	Cradle	102.9	226.912
	Scintillator Rack (Each)	195.4	430.821
Lower Cradle Loaded		**516.2**	**1137.953**
	Cradle	102.9	226.912
	Scintillator Rack (Each)	195.4	430.821
Spectrometer Loaded		**11227.1**	**24751.418**
	Scintillator Rack (Each)	195.4	430.821
	Base Plate (Each)	128.5	283.229
	Vertical Support (Each)	14.1	31.104
	Lower Spectrometer Column Pack (Each)	79.0	174.145
	Upper Spectrometer Column Pack (Each)	83.0	182.953
	Steel Slab (Each)	1099.5	2 423.989
	Steel Spacer (Each)	52.3	115.319
	Center Steel Spacer	50.5	111.349
Steel Ladder		**128.9**	**284.205**
Guardrail Assembly		**566.4**	**1248.769**
	Front and Back Assembly	113.0	249.21
	Right Side Assembly (Short to fit at Carleton)	164.2	361.984
	Corner Assembly	82.1	180.992
	Left Side Assembly (Short to fit at Carleton)	171.4	377.771
Upper Tower Assembly		**1088.0**	**2398.627**
	Front and Back Assembly	102.5	226.078
	Right Side Assembly	144.5	318.467
	Left Side Assembly	141.1	310.996
Middle Tower Assembly		**1108.7**	**2444.23**
	Cantilever Support Right Side	218.7	482.197
	Cantilever Support Left Side	233.6	515.009
	Column (Each)	80.8	178.136
	Beam (Each)	56.8	125.282
	Angle Support (Each)	68.4	150.902
	Cantilever Horizontal Support (Each)	35.4	77.942

U

Lower Tower Assembly		**2584.9**	**5709.796**
	Column (Each)	156.1	344.166
	Beam Front	206.4	455.051
	Beam Rear	240.9	531.074
	Cross Beam - 4x12 (Each)	235.8	519.775
	Rear Floor Plate Assembly	348.9	769.118
	Middle Floor Plate	264.0	582.071
	Front Floor Plate	299.5	660.274
	Cross Brace (Each) - Approximate	16.2	35.719
Cargo Container Loaded		**73.0**	**160.926**
Concrete Foot Pad, Left		**518.6**	**1143.22**
Concrete Foot Pad, Right		**489.5**	**1079.104**
4xT-Sections		**69.1**	**152.308**
	T-Section (Each)	17.3	38.077
Floor Pans		**517.1**	**1139.944**
	Front and Back Assembly	116.8	257.476
	Right Side Assembly	141.9	312.847
	Left Side Assembly	136.7	301.462
Total:		**19403.5**	**42788.453**

Appendix B

Cradle Assembly



Appendix C

Spectrometer Assembly

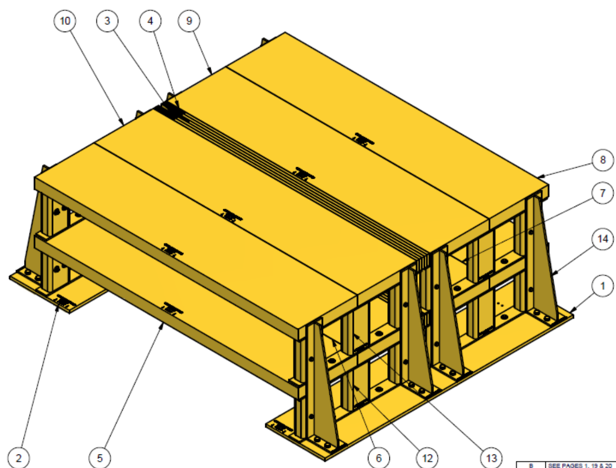
GENERAL NOTES:

1. ALL HOLE DIMENSIONS ARE IN IMPERIAL UNIT INCHES.

ASSEMBLY PROCEDURE:

1. PAINT ALL VISIBLE SURFACES USING ITEM #22.
2. APPLY LABELLING WHERE APPLICABLE USING ITEM #23.
3. ASSEMBLE PER INSTRUCTIONS INDICATED WITHIN THIS DRAWING.
4. WHEN NOTIFIED, DIS-ASSEMBLE.
5. WHEN NOTIFIED, TRANSPORT TO NEW LOCATION.
6. WHEN NOTIFIED, RE-ASSEMBLE.
7. WHEN NOTIFIED, APPLY TOUCH-UP PAINT, ITEM #22, AS REQUIRED.

B TYPOGRAPHICAL ERROR



ITEM	QTY	PART NUMBER	DESCRIPTION	VENDOR	MASS
23	AR		SELF ADHESIVE LABEL		
22	AR	27097X 155	PAINT, TREMCLAD [YELLOW]	THE HOME DEPOT	
21	16	92865A714	Hex Bolt, 1/2-13 unc - 1.25	McMASTER CARR	
20	32	94811A235	Hex Nut, 1/2-13	McMASTER CARR	
19	48	94744A293	Washer, Plain, 1/2	McMASTER CARR	
18	32	98023A033	Washer, Plain, 1/2	McMASTER CARR	
17	32	92865A734	Hex Bolt, 1/2-13 UNC - 5.5	McMASTER CARR	
16	32	90850A400	Washer, Plain, 3/4	McMASTER CARR	
15	32	92865A837	Hex Bolt, Heavy, 3/4-10 UNC - 1.25	McMASTER CARR	
14	8	CPDO-MRD-AS-6035	GUSSET, SPECTROMETER SUPPORT		31.104 kg
13	4	CPDO-MRD-AS-6023	SUPPORT, SPECTROMETER, UPPER		82.986 kg
12	4	CPDO-MRD-AS-6022	SUPPORT, SPECTROMETER, LOWER		78.991 kg
11	6	CPDO-MRD-PT-6808	BAR, ROUND, STEEL, 3/4" DIA.		0.398 kg
10	1	CPDO-MRD-PT-6827	SLAB, IRON, 4" THK		1099.306 kg
9	1	CPDO-MRD-PT-6826	SLAB, IRON, 4" THK		1099.329 kg
8	2	CPDO-MRD-PT-6825	SLAB, IRON, 4" THK		1099.503 kg
7	1	CPDO-MRD-PT-6807	SLAB, IRON, 4" THK		1099.308 kg
6	1	CPDO-MRD-PT-6824	SLAB, IRON, 4" THK		1099.280 kg
5	2	CPDO-MRD-PT-6806	SLAB, IRON, 4" THK		1099.475 kg
4	8	CPDO-MRD-PT-6823	PLATE, STEEL, 1" THK		52.308 kg
3	2	CPDO-MRD-PT-6803	PLATE, STEEL, 1" THK		50.507 kg
2	1	CPDO-MRD-PT-6815	PLATE, STEEL, 1" THK		283.305 kg
1	1	CPDO-MRD-PT-6800	PLATE, STEEL, 1" THK		283.229 kg

APPROXIMATE WEIGHT OF SPECTROMETER: 10,843 kg

AS-BUILT DRAWING MARKED UP WITH GRADE 5 HARDWARE

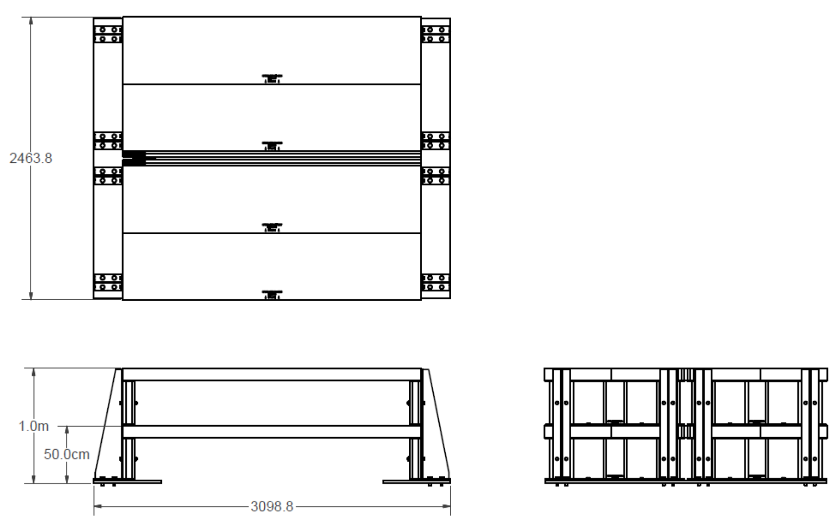
REV.	DESCRIPTION	DATE	APP.
B	SEE PAGES 1, 19 & 20	27-05-2011	
A	FOR PRODUCTION	20-05-2011	V.S.

TOLERANCE X. ±1 ANGLE ±1° X.X ±0.5 X.XX ±0.25 X.XXX ±0.13 INTERPRET DIMENSIONS AND TOLERENCES PER ANSI Y14.5M.
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS IN MM [IN]

DRAWN K. BROWN DATE 3/25/2011 CHECKED DATE APPROVED DATE MATERIAL FINISH NOTES

CARLETON UNIVERSITY PHYSICS DEPARTMENT
2240 HERZBERG LABORATORIES
1125 COLONEL BY DRIVE
OTTAWA, ONTARIO K1S 5B6 CANADA
TEL: (613) 520-2600 ext. 4308
FAX: (613) 520-2569

TITLE ASSEMBLY, WELDMENT, SPECTROMETER
PROJECT: CRIPT TOWER
SIZE A3 SCALE NTS REVISION B SHEET 1 OF 22
DRAWING # CPDO-MRD-AS-6002



FRONT VIEW

REV.	DESCRIPTION	DATE	APP.
B	SEE PAGES 1, 19 & 20	27-05-2011	
A	FOR PRODUCTION	20-05-2011	V.S.

TOLERANCE X. ±1 ANGLE ±1° X.X ±0.5 X.XX ±0.25 X.XXX ±0.13 INTERPRET DIMENSIONS AND TOLERENCES PER ANSI Y14.5M.
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS IN MM [IN]

DRAWN K. BROWN DATE 3/25/2011 CHECKED DATE APPROVED DATE MATERIAL FINISH NOTES

CARLETON UNIVERSITY PHYSICS DEPARTMENT
2240 HERZBERG LABORATORIES
1125 COLONEL BY DRIVE
OTTAWA, ONTARIO K1S 5B6 CANADA
TEL: (613) 520-2600 ext. 4308
FAX: (613) 520-2569

TITLE ASSEMBLY, WELDMENT, SPECTROMETER
PROJECT: CRIPT TOWER

SIZE A3 SCALE NTS REVISION B SHEET 2 OF 22
DRAWING # CPDO-MRD-AS-6002

Appendix D

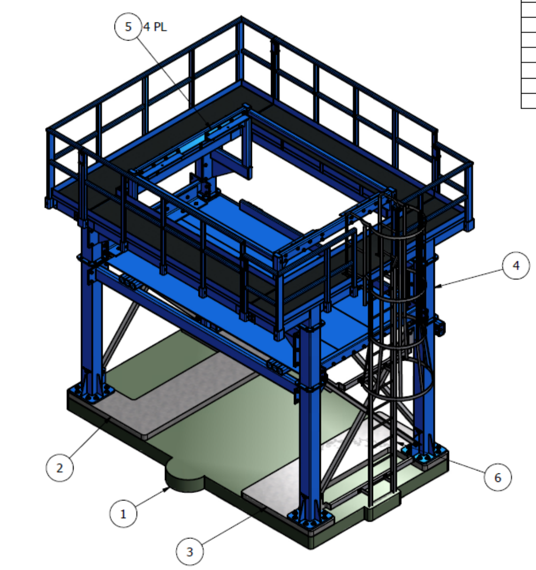
Tower Assembly

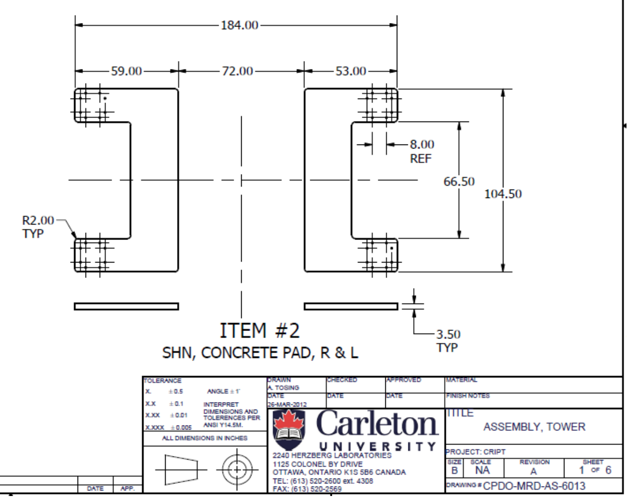
NOTE:

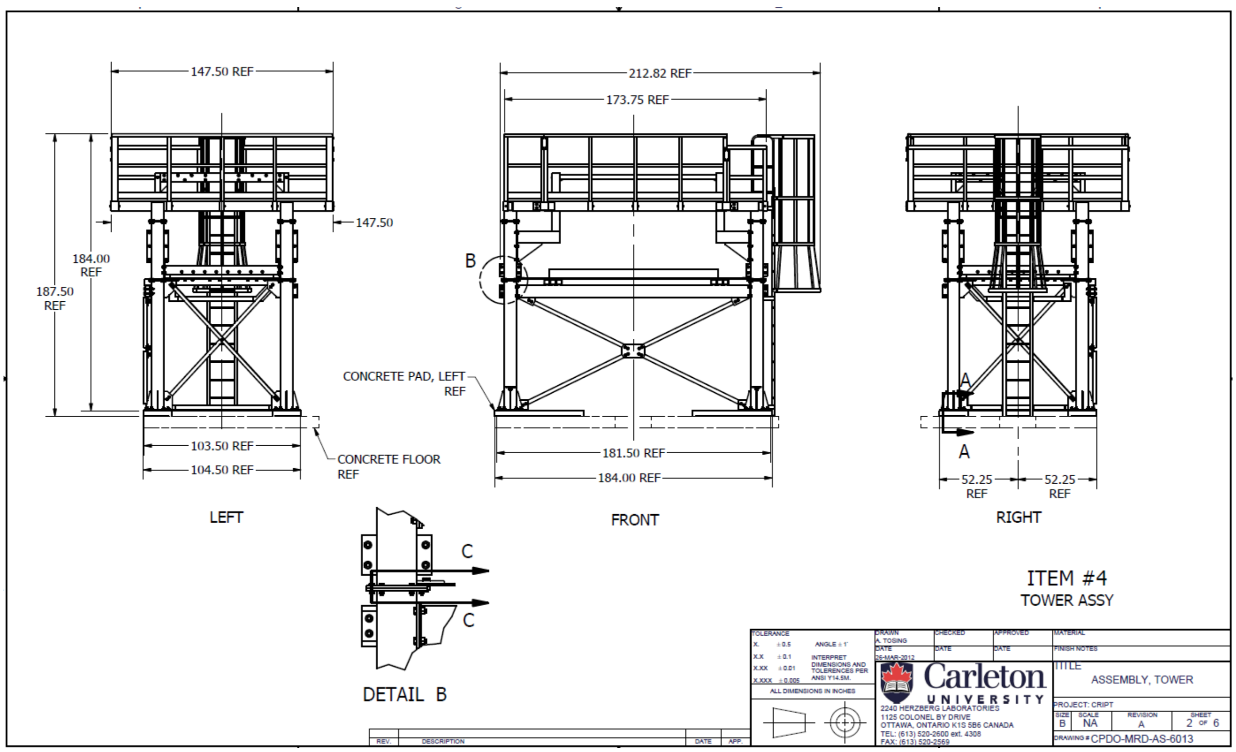
1. PAGE 6, LADDER MOUNT ASSY & MOUNTING LOCATIONS ARE PRELIMINARY AND ARE FOR REFERENCE ONLY.

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION	VENDOR
13	128	98038A265	Plain Steel Structural Washer, 1/2", 1-1/16" OD, .09"-.18" Thick	McMASTER-CARR
12	56	98038A274	Plain Steel Structural Washer 3/4", 1-15/32" OD, .09"-.18" Thick	McMASTER-CARR
11	64	90580A315	HVy Hex Structural Nut 1/2"-13, 7/8" W, 31/64" H	McMASTER-CARR
10	28	90580A325	Hvy Hex Structural Nut 3/4"-10, 1-1/4" W, 47/64" H	McMASTER-CARR
9	64	91571A254	Plain Steel Hvy Hex Head Structural Bolt 1/2"-13, 2" Length	McMASTER-CARR
8	28	91583A196	Galvanized Hvy Hex Head Structural Bolt 3/4"-10, 4-1/2" L	McMASTER-CARR
7	32	00282538	HILTI KWIK BOLT 3 - EXPANSION ANCHOR, 3/4-10"	Hilti Corporation
6	1	F13WC	FIXED STEEL CAGED LADDER	National Ladder & Scaffold Co
5	4	CPDO-MRD-AS-6089	ASSEMBLY, T-SUPPORT	STC
4	1	CPDO-MRD-AS-6013	ASSEMBLY, TOWER	STC
3	1	FOOTING RIGHT	CONCRETE PAD, RIGHT	CUMBERLAND
2	1	FOOTING LEFT	CONCRETE PAD, LEFT	CUMBERLAND
1	REF	GROUND LEVEL	GROUND LEVEL	EXISTING

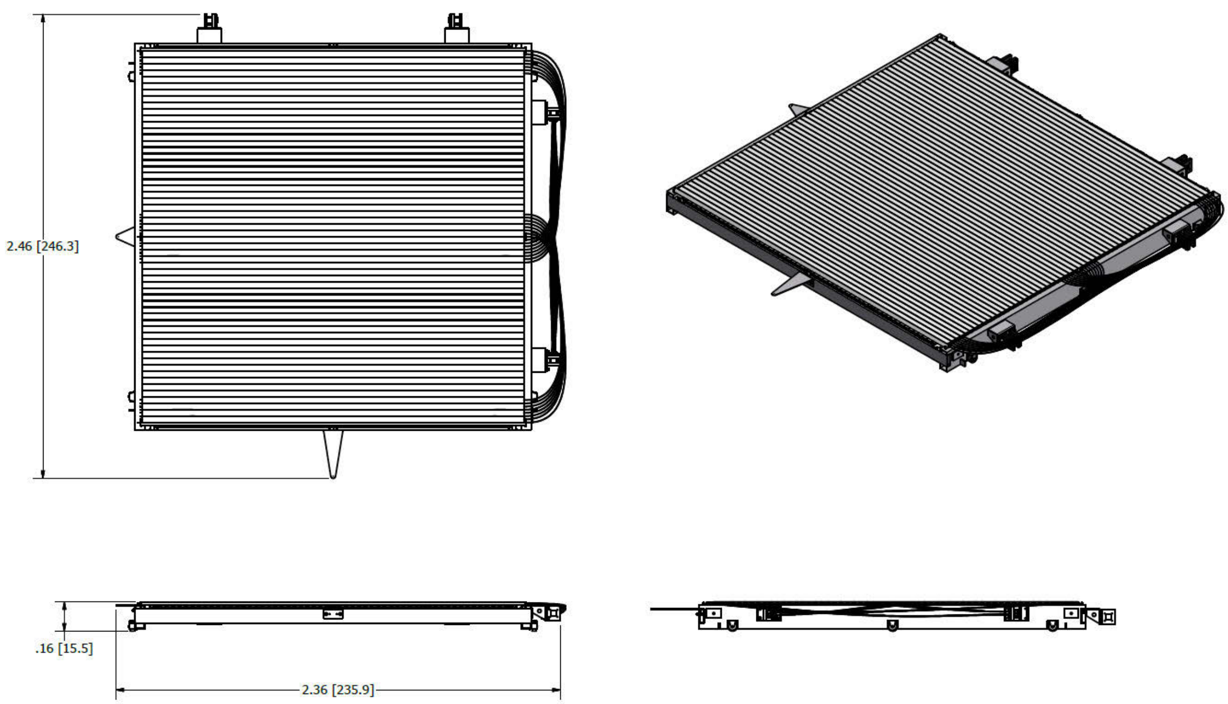






Appendix E

Scintillator Module



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4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Jonkmans, Guy

5. DATE OF PUBLICATION (Month and year of publication of document.) April 2014	6a. NO. OF PAGES 39	6b. NO. OF REFS 21

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Final Report

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DRDC CSS

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14. KEYWORDS, DESCRIPTORS or IDENTIFIERS

.Radiobioassy; RN Monitoring; Muon Cargo; Medical Casualty Management